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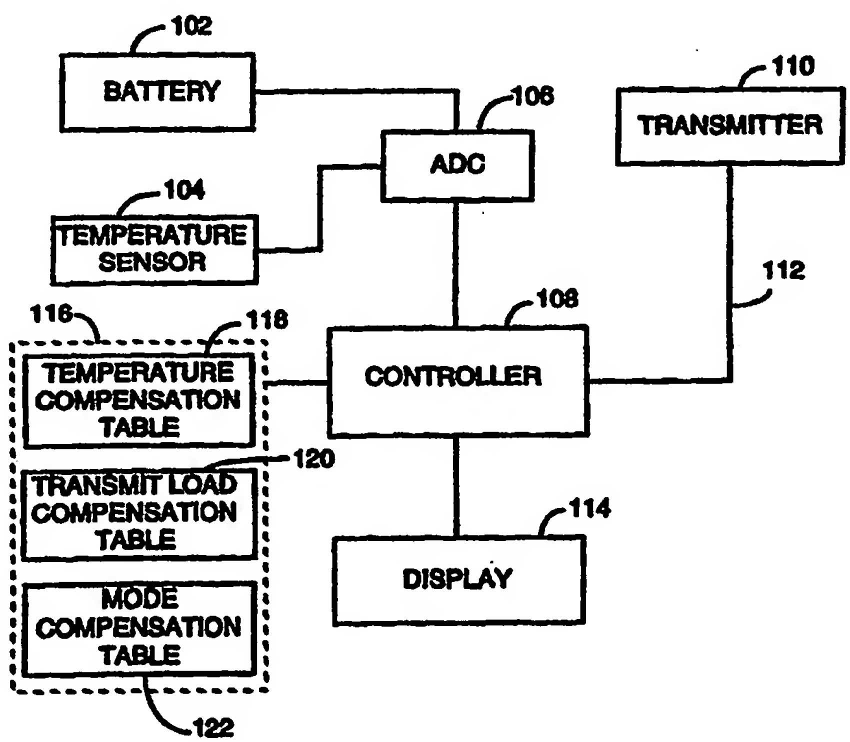
(54) Title: METHOD AND APPARATUS FOR BATTERY GAUGING IN A PORTABLE COMMUNICATION DEVICE

(57) Abstract

A method and apparatus for determining the remaining battery capacity in a portable communication device. The capacity determination circuit includes a converter (106) for measuring a battery voltage of the battery (102), a temperature sensor (104) for measuring a battery temperature of the battery, and a controller (108) for sampling the transmit power control signal. The controller calculates a corrected capacity value in response to the battery voltage, the battery temperature, the power control signal, and an operational mode of the portable communication device. Optionally, the controller (108) may determine a transmit duty cycle of the variable gain transmitter (110), and calculate the corrected capacity value in further response to the transmit duty cycle. By correcting for the effects of temperature, transmit load, operational mode, and optionally the transmit duty cycle, the present invention provides a more accurate indication of remaining battery capacity to the user.



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METHOD AND APPARATUS FOR BATTERY GAUGING IN A PORTABLE COMMUNICATION DEVICE

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates to wireless communication devices. More particularly, the present invention relates to a novel and improved method and apparatus for determining an accurate measure of the remaining capacity of a battery in a portable communication device.

II. Description of the Related Art

Portable communication devices, such as cellular or PCS radiotelephones, typically include a rechargeable or replaceable battery which supplies power to the portable communication device when it is not connected to an external power source such as an AC adapter or vehicle adapter. The remaining capacity (i.e., talk time) of the battery is typically displayed visually to the user on a display by presenting a number of "bars" or a thermometer-style display. By monitoring the displayed battery capacity, the user knows when to replace or recharge the battery. Clearly, if the user is able to recharge or replace the battery before it "dies" (i.e., runs out of power), the user may avoid dropping a call in progress, or not being able to make a call because of a "dead" battery. The more accurate the battery capacity gauging technique used in the portable communication device, the better the user is able to rely on the displayed capacity. An accurate battery guage also allows the phone to warn the user when the battery is nearly out of power so that the user can wrap up a call before changing batteries.

The capacity of a battery is typically expressed as the total quantity of electricity involved in the electro-chemical reaction and is defined in ampere-hours or watt-hours. Although the theoretical capacity of a battery is dependent only on the quantity and type of chemicals used as the reactants, there are several other factors that affect the actual battery capacity. One large contributing factor to the capacity of a battery is the internal impedance of the cell. The internal impedance causes a voltage drop during operation, and also consumes part of the useful energy of the battery as heat The voltage drop due to internal impedance is usually referred to as "ohmic polarization" or IR drop and is proportional to the current drawn from the

battery. This IR drop is ohmic in nature, and follows Ohm's law, with a linear relationship between current and voltage drop.

Thus, a first portable communication device that draws a relatively large amount of current will have a lower actual battery capacity than a second portable communication device that draws a relatively small amount of current from the same type of battery. Furthermore, a dual-mode portable communication device, such as one that operates on a Code-Division Multiple Access (CDMA) wireless communication system when in a CDMA mode, and on an analog wireless communication system such as an AMPS system when in an analog mode, may draw different current when in the CDMA mode than when in the analog mode. Thus, the dual-mode portable communication device may have a different battery capacity when in the CDMA mode than in the analog mode. Furthermore, there may be many more operational modes that represent different loads on the battery, including idle modes, sleep modes, transmit modes, receive only modes, and backlighted modes. Each of these modes will cause different current to be drawn from the battery, and will affect the battery life.

Another factor that has a great influence on actual battery capacity is temperature. Because a battery generates electricity from an electro-chemical reaction, it will exhibit a lower capacity at lower temperatures than it will at moderate temperatures. This is due to the reduction in chemical activity and the increase in battery internal resistance at lower temperatures. For example, a battery that provides a two-hour talk time at 50C may only provide 20 minutes of talk time at -10C. There is also a relationship between the IR drop and the temperature drop. As stated above, as the discharge rate is increased (i.e., more current is drawn), the cell voltage decreases. The rate of voltage decrease is usually more rapid at lower temperatures. Similarly, the cell's capacity falls off most rapidly with increasing discharge load and decreasing temperature. It should be noted that the ideal operating temperature of a battery is not the maximum operating temperature of the battery, and thus an increase or a decrease in temperature from the ideal operating temperature may have an adverse effect on battery life.

Each of these factors complicates the determination of battery capacity for display to the user. A simple battery gauging method that merely measures the voltage at the battery terminals will be in error because of the IR drop (which lowers the voltage) and the temperature drop (which reduces the capacity). In other words, this simple battery gauging method will result in a display that the battery has more or less remaining capacity than it actually does have. This can cause the user to unintentionally drop a

call in progress, or alternatively, to change the battery more frequently than is necessary. What is needed is a battery gauging method and apparatus that accurately determines the remaining battery capacity.

SUMMARY OF THE INVENTION

The present invention is a novel and improved method and apparatus for determining the remaining battery capacity in a portable communication device. The portable communication device has a variable gain transmitter which is controlled by a power control signal. The capacity determination circuit includes at least a sampler for sampling the transmit power control signal. The circuit also may include a converter for measuring a battery voltage of the battery, and a temperature sensor for measuring a battery temperature of the battery. The controller calculates a corrected capacity value in response to at least the power control signal. The controller also may determine the corrected capacity value in response to the battery voltage, and the battery temperature.

Additionally, the controller determines an operational mode of the portable communication device and calculates the corrected capacity value in further response to the operational mode. Optionally, the controller may determine a transmit duty cycle of the variable gain transmitter, and calculate the corrected capacity value in further response to the transmit duty cycle.

The circuit further comprises a memory element for storing a transmit load compensation table. The controller retrieves transmit load correction factors from the transmit load compensation table in response to the power control signal. A memory element also stores a mode compensation table. The controller retrieves operational mode correction factors from the mode compensation table in response to the operational mode.

The circuit measures the battery voltage and temperature, and accesses a temperature compensation table to determine a temperature-compensated capacity value. The circuit applies the transmit load correction factor and the mode correction factor to the temperature-compensated capacity value to generate the corrected capacity value. The corrected capacity value is then displayed to the user on a display. In alternate embodiments, the correction factors may be calculated by using an appropriately descriptive mathematical function rather than using data stored in tables.

By correcting for the effects of temperature, transmit load, operational mode, and optionally the transmit duty cycle, the present invention provides a more accurate indication of remaining battery capacity to the user.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIG. 1 is an illustration of the battery gauging apparatus of the present invention in block diagram format; and

FIG. 2 is a flowchart of the method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates the battery gauging apparatus of the present invention. The present invention is intended for use in a portable communication device. However, for clarity and simplicity, only those components of the portable communication device that are necessary for an understanding of the present invention are shown in FIG. 1.

Controller **108** calculates a corrected capacity value in response to a measured voltage of battery **102**, as corrected by capacity correction factors stored within various tables in memory **116** as will be discussed further below. In response to the corrected capacity value controller **108** displays a visual indication of remaining battery capacity on display **114**.

Battery **102** generates a voltage as is known in the art. The battery voltage is sampled and converted to a digital voltage signal representative of the magnitude of the battery voltage by analog-to-digital converter (ADC) **106**. ADC **106** provides this digital voltage signal to controller **108**. In the preferred embodiment, battery **102** is a rechargeable battery such as a nickel-cadmium, nickel metal hydride, or lithium ion type battery. However, it should be noted that battery **102** may be any type of battery known in the art, including disposable "off the shelf" alkaline types of batteries. It also should be noted that the sampling rate of the battery voltage by ADC **106** is not critical to the present invention, but in the preferred embodiment is on the order of twice per second.

Temperature sensor **104** is located in close proximity to battery **102**, and senses a temperature of battery **102**. Temperature sensor **104** generates an analog temperature signal in response to the temperature of battery **102**. ADC **106** receives the analog temperature signal from temperature sensor **104** and samples and converts it to a digital temperature signal representative of the temperature of battery **102**. ADC **106** provides this digital temperature signal to controller **108**. In the preferred embodiment, temperature sensor **104** comprises at least a thermistor whose impedance is temperature dependent, and associated circuitry as is known in the art for measuring temperature. The sampling rate of the temperature signal by ADC **106**, like that of the battery voltage, is not critical to the present invention, and is likewise on the order of twice per second.

Using the digital voltage signal and the digital temperature signal, controller **108** is able to access temperature-corrected capacity values contained in temperature compensation table **118** located within memory **116**. Temperature compensation table **118** contains temperature-corrected capacity values, indexed by a temperature value and a voltage value combination. These capacity values describe the nominal shape of the discharge curve of the battery **102** (voltage vs. time) over the operating voltage range and the operating temperature range.

As stated above, the capacity of a battery is generally proportional to the temperature (within the operating range), and generally inversely proportional to the drop in voltage due to internal IR effects. Thus, for each quantitized temperature/voltage combination within the operating range of the portable communication device, a corresponding capacity value exists in temperature compensation table **118**. For example, at a low temperature and low battery voltage combination, temperature compensation table **118** would contain a corresponding capacity value describing the point on the discharge curve for that voltage and temperature combination. Thus, the present invention increases the accuracy of the capacity value due to variations over temperature and voltage.

Controller **118** also provides a transmit power control signal to transmitter **110** over signal line **112**. As is well known in the art, transmit power control signal controls the transmit power of, and thus the current load drawn by, a power amplification chain (not shown) in transmitter **110**. For example, when the portable communication device is far from the base station with which it is communicating, it will turn up its transmit power by increasing the magnitude of the transmit power control signal to transmitter **110**. Examples of transmit power control may be found, for example, in U.S.

Patent No. 5,452,473, issued September 19, 1995, entitled "REVERSE LINK, TRANSMIT POWER CORRECTION AND LIMITATION IN A RADIOTELEPHONE SYSTEM," assigned to the assignee of the present invention and incorporated herein by reference.

In the present invention, a digital representation of the magnitude of the transmit power control signal generated by controller **118** is used to access transmit power correction factors contained in transmit load compensation table **120**. This digital power control signal is sampled from a register (not shown) in controller **108** at a rate that is proportional to the discharge constant of the battery. Although the exact sampling period is not critical to the present invention, it should be long enough that the effects of a change in the transmit load on the instantaneous battery voltage have been dampened. As stated above, the current load on the battery causes a voltage drop at the battery terminals which is proportional to the magnitude of the current load. Thus, for each quantitized transmit power control signal value within the operating range, a corresponding transmit power correction factor exists in transmit load compensation table **120**. For example, for a high transmit power level, transmit load compensation table **120** would contain a corresponding transmit power correction factor to be applied to the capacity value to more accurately reflect the effect of transmit load on battery capacity. It should be noted that the verb "applied" is used herein in its broad sense, and includes morphing or spline functions as well as simpler mathematical operations such as addition or subtraction.

Controller **108** also controls the operational mode of the portable communication device. For example, in a dual-mode CDMA/FM portable communication device, there may be four operational modes: CDMA transmit, CDMA receive, FM transmit, and FM receive. Different circuits within the portable communication device are operational (i.e., have power applied and are functioning) during different operational modes. For example, during CDMA receive mode, the FM modulation and demodulation circuitry may be powered down, and vice versa. As a result, each operational mode may draw a different amount of current. In order to account for the effect of these different operational modes on battery capacity, controller **108** accesses mode correction factors contained in mode compensation table **122**. For each operational mode, a corresponding mode correction factor exists in the mode compensation table **122**. For example, if the dual-mode CDMA/FM portable communication device described above were operating in the CDMA receive mode, a corresponding mode correction factor from mode compensation table **122** would be applied to the

capacity value to more accurately reflect the effect of varying current load among the different operational modes.

In order to calculate the corrected capacity value for display to the user on display **114**, controller **108** applies each of the capacity correction factors discussed above to the measured voltage of battery **102**. Optionally, controller **108** also accounts for the transmit duty cycle, for example, in a digital communication system such as that described in U.S. Patent No. 5,103,459, entitled "SYSTEM AND METHOD FOR GENERATING SIGNAL WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM," assigned to the assignee of the present invention and incorporated herein by reference. In the just-mentioned patent, data is transmitted at various data rates: full rate, half rate, quarter rate, and eighth rate. In full rate transmission, the transmitter **110** transmits substantially continuously throughout the duration of each data frame. In half rate, since there is only half as much data to transmit, transmitter **110** transmits only half the time (i.e., gates on and off at a 50% duty cycle) during each data frame. Similarly, for quarter rate, transmitter **110** transmits at a 25% duty cycle, and for eighth rate, transmitter **110** transmits at a 12.5% duty cycle.

Since the duty cycle (i.e., the gating on and off) of transmitter **110** is not controlled by the transmit power control signal on line **112**, the controller **108** may multiply the transmit load correction factor from transmit load compensation table **120** by the present transmit duty cycle to more accurately reflect the effect of transmit duty cycle on the transmit load, and thus on the battery capacity. Controller **108** may sample the frame rate over a period that is proportional to the discharge constant of the battery **102** in order to avoid errors caused by recovery time of the battery **102** after a sudden change in transmit power or duty cycle. In the preferred embodiment, the frame rate sampling period is equal to the transmit power control signal sampling period. It should be noted that in a real system, there are some guard times and switching times which make the fractional data rates different from the actual transmit duty cycle. For example, the 1/2 data rate produces a duty cycle that is somewhat less than 50% due to the finite switching and guard times. Thus, it is desirable to account for these overhead times when correcting for the transmit duty cycle.

FIG. 2 is a flowchart of the method of the present invention. It should be noted that although the steps 200-208 are illustrated in a given order, the order of these steps is not critical to the present invention, and clearly may be performed in any sequence prior to calculation step 210.

The flow begins at step **200** where the battery **102** voltage is measured as described above, and the resulting measurement, V, is provided to controller **108**. In step **202**, the battery **102** temperature, T, is measured as described above by temperature sensor **104**, and provided to controller **108**. At step **204**, the transmit power control signal value, G, is sampled by controller **108** as described above. At optional step **206**, the transmit duty cycle is determined by controller **108** as described above. At step **208**, the operational mode, M, is determined by controller **108** as described above.

With each of these measurements, controller **108** may calculate the corrected capacity value in step **208**. A general formula that controller **108** uses to calculate the corrected capacity value in the present invention is as follows:

$$\text{Capacity (scaled units)}= \text{TEMP}(V,T)+\text{LOAD}_{TX}(G)\times K(\text{duty cycle}) + \text{LOAD}_{MODE}(M) \qquad (1)$$

where:

TEMP(V,T) is the capacity value from temperature compensation table **118**;
$\text{LOAD}_{TX}(G)$ is the transmit load correction factor from transmit load compensation table **120**;
K(duty cycle) is the transmit duty cycle; and
$\text{LOAD}_{MODE}(M)$ is the operational mode correction factor from mode compensation table **122**.

In step **212**, controller **108** displays the corrected capacity value on display **114** for presentation to the user of the portable communication device. Alternately, in step **212** the display may be an audio indication or warning that there is only a certain time remaining on this battery, giving the user the opportunity to end the call before switching batteries. The method of FIG. 2 may repeat once every half-second or so in order to provide an updated capacity display to the user. In this manner, the user is provided with an accurate representation of remaining battery capacity that accounts for the errors introduced by temperature, transmit load, operational mode, and optionally, the transmit duty cycle. Thus, the user can avoid dropping a call in progress, or swapping out batteries more often than is necessary.

It should be noted that other operating mode tables may be used in other embodiments, or that the exemplary operating mode tables

represented here may be partially or totally combined. It also should be noted that since many portable radiotelephones use several different types and sizes of batteries (i.e., low capacity, high capacity, Nickel-Cadmium, Lithium Ion), a corresponding set of tables shown above may exist for each of the different types of batteries, with each different set of tables containing correction factors applicable to one of the different battery types. Additionally, it should be noted that the correction factors listed above are merely exemplary and that other mathematical correction techniques may be employed. For example, a correction factor could be merely an offset, or it may be more generally a factor which is applied to the discharge curve. Finally, it should be noted that in other embodiments, only a subset of the above described correction factors may be used. For example, the power control signal and the operating mode, or the power control signal and the battery voltage. Other combinations are readily apparent to one skilled in the art, and the present invention is intended to be limited only by the below-appended claims.

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

I CLAIM:

CLAIMS

1. A method for determining the remaining battery capacity in a portable communication device having a battery and a variable gain transmitter which is controlled by a power control signal, the method comprising the steps of:

sampling said power control signal; and

calculating a corrected capacity value in response to said power control signal.

2. The method of claim 1 further comprising the step of measuring a battery temperature of said battery and wherein said step of calculating a corrected capacity value is performed in further response to said measured battery temperature.

3. The method of claim 1 further comprising the step of measuring a battery voltage of said battery, and wherein said step of calculatinga corrected capacity value is performed in further response to said measured battery voltage.

4. The method of claim 1 further comprising the step of determining an operational mode of said portable communication device and wherein said step of calculating a corrected capacity value is performed in further response to said operational mode.

5. The method of claim 1 further comprising the step of determining a transmit duty cycle of said variable gain transmitter, and wherein said step of calculating a corrected capacity value is performed in further response to said transmit duty cycle.

6. The method of claim 1 wherein said step of calculating a corrected capacity value further comprises the step of determining a transmit load correction factor in response to said power control signal.

7. The method of claim 4 wherein said step of calculating a corrected capacity value further comprises the step of determining an operational mode correction factor in response to said operational mode.

8. A circuit for determining the remaining battery capacity in a portable communication device having a variable gain transmitter which is controlled by a power control signal, the circuit comprising:

a sampler for sampling said power control signal; and

a controller for calculating a corrected capacity value in response to said power control signal.

9. The circuit of claim 8 further comprising a converter for measuring a battery voltage of said battery, and wherein said controller calculates said corrected capacity value in further response to said measured battery voltage.

10. The circuit of claim 8 further comprising a temperature sensor for measuring a battery temperature of said battery, and wherein said controller calculates said corrected capacity value in further response to said measured battery temperature.

11. The circuit of claim 8 wherein said controller is further for determining an operational mode of said portable communication device and wherein said controller calculates said corrected capacity value in further response to said operational mode.

12. The circuit of claim 8 wherein said controller is further for determining a transmit duty cycle of said variable gain transmitter, and wherein said controller calculates said corrected capacity value in further response to said transmit duty cycle.

13. The circuit of claim 8 further comprising a memory element for storing a transmit load compensation table, and wherein said controller retrieves transmit load correction factors from said transmit load compensation table in response to said power control signal.

14. The method of claim 11 further comprising a memory element for storing a mode compensation table, and wherein said controller retrieves operational mode correction factors from said mode compensation table in response to said operational mode.

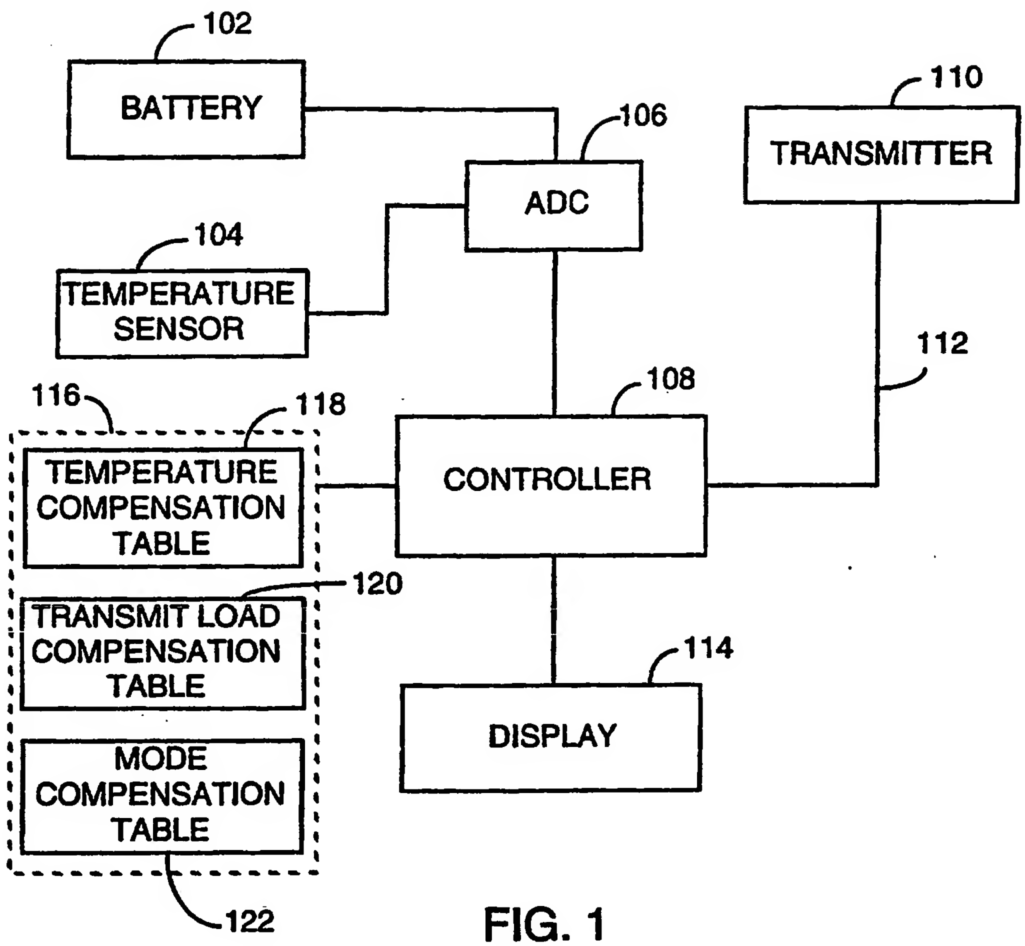
102
BATTERY
106
ADC
110
TRANSMITTER
104
TEMPERATURE SENSOR
112
116
118
108
TEMPERATURE COMPENSATION TABLE
CONTROLLER
120
TRANSMIT LOAD COMPENSATION TABLE
114
DISPLAY
MODE COMPENSATION TABLE
122

FIG. 1

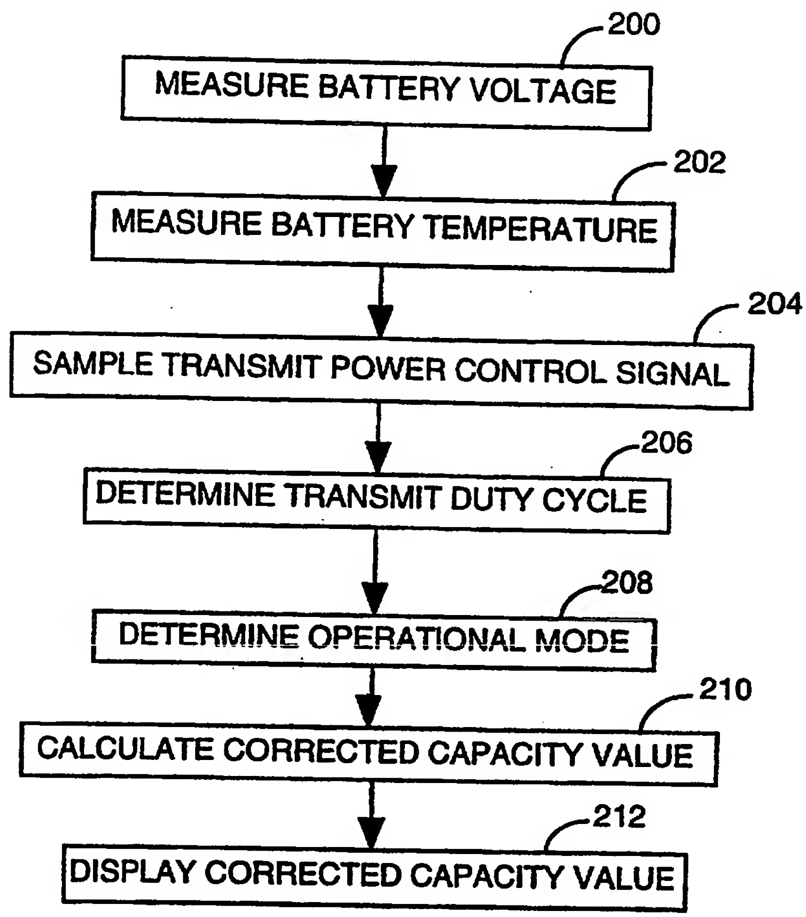
200
MEASURE BATTERY VOLTAGE
202
MEASURE BATTERY TEMPERATURE
204
SAMPLE TRANSMIT POWER CONTROL SIGNAL
206
DETERMINE TRANSMIT DUTY CYCLE
208
DETERMINE OPERATIONAL MODE
210
CALCULATE CORRECTED CAPACITY VALUE
212
DISPLAY CORRECTED CAPACITY VALUE

FIG. 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/23869

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01R31/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP 0 593 198 A (MATSUSHITA) 20 April 1994 see column 3, line 25 - column 4, line 42; figure 1	1,3,8,9 2,4,10,11
Y	EP 0 496 537 A (IBM) 29 July 1992 see abstract	2,10
Y A	EP 0 592 965 A (SANYO ELECTRIC) 20 April 1994 see abstract; figure 1	4,11 13,14
A	EP 0 546 569 A (FUJITSU) 16 June 1993	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 March 1999	17/03/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Iwansson, K

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 98/23869

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